USAF Inorganic Coating Successes

Elizabeth Berman, Ph.D.
Air Force Research Laboratory
Materials and Manufacturing Directorate

Integrity ★ Service ★ Excellence

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE	2. REPORT TYPE	3. DATES COVERED
AUG 2012		**00-00-2012 to 00-00-2012**

4. TITLE AND SUBTITLE	5a. CONTRACT NUMBER
USAF Inorganic Coating Successes	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Air Force Research Laboratory,Materials and Manufacturing Directorate,WPAFB,OH,45433**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S)
	11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES
Presented at the ASETSDefense 2012: Workshop on Sustainable Surface Engineering for Aerospace and Defense August 27-30, 2012, San Diego, CA

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**37**	

Agenda

- Introduction
- Environmental Regulations and Drivers
- AFRL Mission and Approach
- Chromium Replacement Projects
- Cadmium Replacement Projects
- Summary

Environmental Regulations

Restrictions on chromium (Cr), cadmium (Cd), and other air pollutants and environmental toxins are becoming more stringent both nationally and internationally

Air Logistics Center (ALC) Drivers

- **AFRL focus areas**
  - Primary: Cr and Cd replacement
  - Secondary: beryllium (Be), cobalt (Co), and nickel (Ni)
- **Regulatory issues**
  - Regulated by OSHA, EPA, and National Institute for Occupational Safety and Health (NIOSH), among others
    - Usage is restricted for all DoD applications; hexavalent chromium [Cr(VI)] requires a waiver for use
    - Cr(VI) are on the DoD's Emerging Contaminants Action List
    - Cd is on the DoD's Emerging Contaminants Watch List
  - Regulatory enforcement is becoming a concern

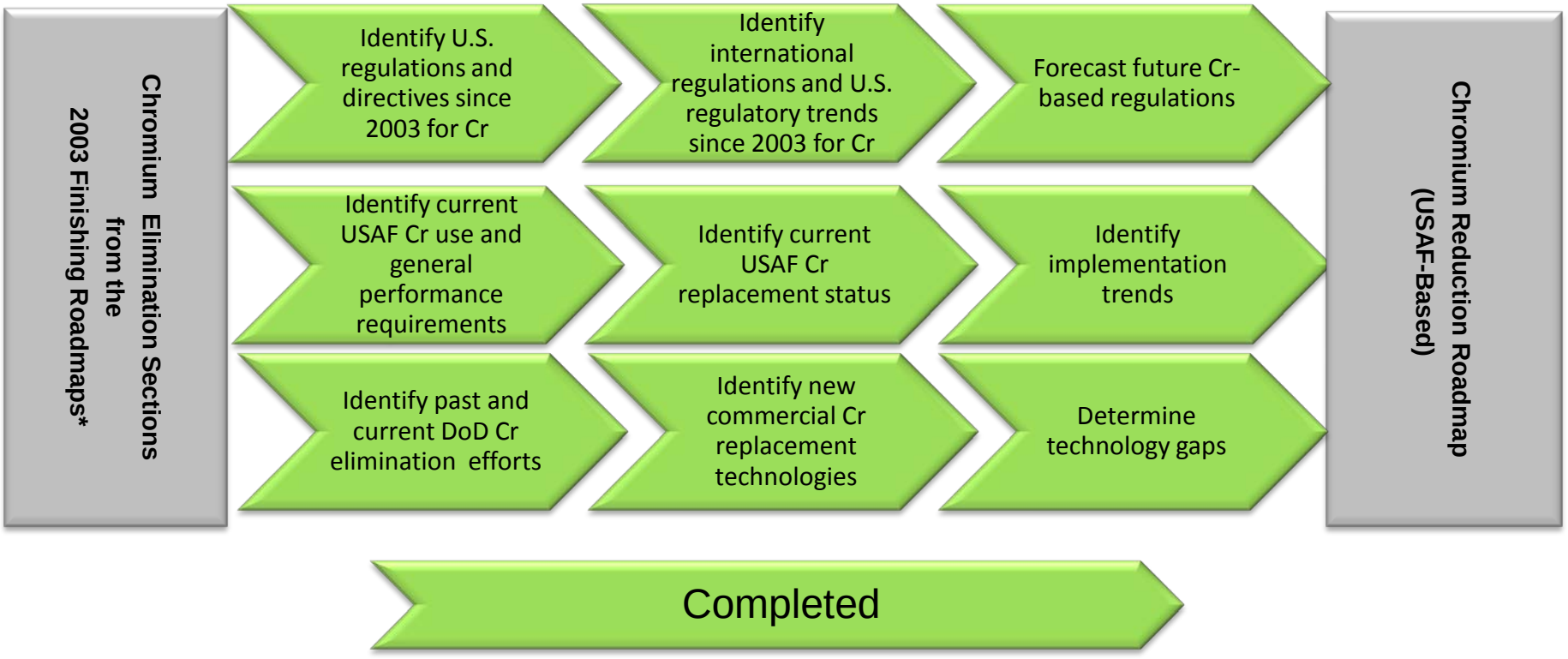
ALC Drivers

- **Environmental, safety, and occupational health (ESOH) issues**
  - Cd and hexavalent chromium (Cr[VI]) are classified as toxic
  - Cr(VI) compounds are genotoxic carcinogens
  - Cd is a toxin and Cd plating involves cyanides
- **High costs associated with compliance**
  - Workplace safety features (personal protective equipment, ventilation, filtration, tank covers, etc.)
  - Cd has a limited and decreasing numbers of vendors

AFRL Approach

- **Identify legal requirements restricting material use**
  - Review current U.S. regulations/directives
  - Identify international regulations
  - Speculate on future regulations/directives based on regulatory trends
- **Review USAF usage of materials and solutions**
  - Focus on high-priority problems/needs
- **Identify replacement technologies and correct gaps**
  - Identify newly developed commercial solutions
- **Test, validate, and implement replacement technologies**
  - Conduct applied research & development (R&D), as required

Cr Roadmap Development Approach and Status



* U.S. Air Force Inorganic Finishing Pollution Prevention Technology Roadmap
U.S. Air Force Organic Finishing Pollution Prevention Technology Roadmap

Dichromate Sealer Replacement

Identified, demonstrated/validated, and implementing a chromium-free alternative to sodium dichromate sealer for Type II anodizing processes at Ogden Air Logistics Center (OO-ALC)

Sealer	Coating Process Identification
Sodium dichromate solution, 5-9 oz/gal	Baseline 1
Boiling deionized water	Baseline 2
Unsealed	Baseline 3
Sodium dichromate solution, 50 parts per million	Benchmark
Permanganate Seal	Candidate 1
Low Nickel Seal (with a hot water seal)	Candidate 2A
Low Nickel Seal (without a hot water seal)	Candidate 2B

Summary of Dichromate Sealer Test Results

Sealer	Substrate	Quality	Thickness	Corrosion	Primer	Dry Tape Adhesion	Wet Tape Adhesion
Baseline 1	Al 2024-T3	PASS	PASS	PASS	1	5B	5W
					2	5B	4W
	Al 6061-T6	PASS	PASS	FAIL	1	5B	5W
					2	5B	5W
	Al 7075-T6	PASS	PASS	PASS	1	5B	5W
					2	5B	4W
Baseline 2	Al 2024-T3	PASS	PASS	FAIL	1	3B	4W
					2	3B	2W
	Al 6061-T6	PASS	PASS	FAIL	1	5B	5W
					2	5B	3W
	Al 7075-T6	PASS	PASS	PASS	1	5B	5W
					2	5B	2W
Baseline 3	Al 2024-T3	PASS	PASS	FAIL	1	5B	5W
					2	5B	4W
	Al 6061-T6	PASS	PASS	FAIL	1	5B	5W
					2	5B	3W
	Al 7075-T6	PASS	PASS	PASS	1	5B	5W
					2	5B	5W
Benchmark	Al 2024-T3	PASS	PASS	PASS	1	5B	5W
					2	5B	1W
	Al 6061-T6	PASS	PASS	PASS	1	5B	5W
					2	5B	4W
	Al 7075-T6	PASS	PASS	PASS	1	5B	5W
					2	5B	3W
Candidate 1	Al 2024-T3	PASS	PASS	PASS	1	5B	5W
					2	5B	3W
	Al 6061-T6	PASS	PASS	FAIL	1	5B	4W
					2	5B	0W
	Al 7075-T6	PASS	PASS	PASS	1	5B	4W
					2	5B	3W
Candidate 2A	Al 2024-T3	PASS	PASS	PASS	1	5B	4W
					2	4B	0W
	Al 6061-T6	PASS	PASS	PASS	1	5B	4W
					2	5B	0W
	Al 7075-T6	PASS	PASS	PASS	1	5B	4W
					2	5B	0W
Candidate 2B	Al 6061-T6	PASS	PASS	PASS	1	5B	4W
					2	5B	1W

Dichromate Sealer Path Forward

- **Complete additional corrosion and adhesion testing requested by OO-ALC**
- **Continue assisting OO-ALC with implementing permanganate sealer**
  - Received approval from Engineering Review Board (ERB) to use the permanganate seal for Type II anodizing operations
- **Position OO-ALC for a completely Cr-free surface finishing operation**
  - Anodizing, sealing, and primer application
- **Leverage success for additional aviation applications**
  - Within other ALCs and Army Aviation and Missile Command

Typical Type II Anodizing Operation

Chromium-Free Conversion Coatings for Zinc-Nickel

Identify and evaluate a chromium-free conversion coating (CFCC) for the zinc-nickel (Zn-Ni) plating line at OO-ALC

Coating Process	Conversion Coating Composition	Secondary Sealer
Baseline	Trivalent Chromium (Cr[III]) base	None
Candidate 1-S	Permanganate base	Inorganic silicate
Candidate 1	Permanganate base	None
Candidate 2-S1	Fluorozirconate base	Organic silicate
Candidate 2-S2	Fluorozirconate base	Inorganic silicate
Candidate 2	Fluorozirconate base	None
Candidate 3	Divalent Zn salt base	None

CFCC Zn-Ni Test Results

Test	Test Method	Baseline	Candidate 1		Candidate 1-S		Candidate 2		Candidate 2-S1	Candidate 2-S2		Candidate 3	
Baking Scenario		Baked	Baked	As Coated	Baked	As Coated	Baked	As Coated	Baked	Baked	As Coated	Baked	As Coated
Quality/ Appearance	AMS QQ-P-416	PASS	FAIL	FAIL	FAIL	FAIL	PASS	PASS	PASS	FAIL	PASS	FAIL	FAIL
Adhesion to Zn-Ni	ASTM D 3359, Method A	PASS	PASS	PASS	PASS	PASS	PASS	PASS	PASS	PASS	PASS	PASS	PASS
Paint Adhesion – Cr Primer	ASTM D 3359, Method A	PASS	PASS	PASS	PASS	PASS	PASS	PASS	PASS	PASS	PASS	PASS	PASS
Paint Adhesion – Cr-Free Primer	ASTM D 3359, Method A	PASS	PASS	PASS	PASS	PASS	PASS	PASS	PASS	FAIL	FAIL	PASS	PASS
Corrosion Resistance – Bare/ Unscribed	ASTM B 117	W - PASS	W - FAIL	W – FAIL	W – FAIL	W – FAIL	W – FAIL	W – FAIL	W – PASS	W – FAIL	W – FAIL	W- FAIL	W- FAIL
		R - PASS	R – FAIL	R - FAIL	R - FAIL	R - PASS	R – FAIL	R - FAIL	R - PASS	R - PASS	R - PASS	R – FAIL	R – FAIL
Corrosion Resistance – Bare/ Scribed	ASTM B 117	W - PASS	W – FAIL	W – FAIL	W – FAIL	W – FAIL	W – FAIL	W – FAIL	W – PASS	W – FAIL	W – FAIL	W – FAIL	W - FAIL
		R - PASS	R - FAIL	R - FAIL	R - FAIL	R - FAIL	R - FAIL	R - FAIL	R - PASS	R - PASS	R - PASS	R – FAIL	R - FAIL
Corrosion Resistance – Painted/ Scribed	ASTM B 117	W – PASS	W – PASS	W – PASS	W – PASS	W – PASS	W – PASS	W – PASS	W – PASS	W – PASS	W – PASS	W – PASS	W – PASS
		R - PASS	R - FAIL	R - PASS	R - FAIL	R - PASS	R – PASS	R - PASS	R - PASS	R - PASS	R - PASS	R – PASS	R - PASS
Chemical Composition	ASTM E 1508	N/A	PASS	PASS	PASS	PASS	PASS	PASS	PASS	PASS	PASS	PASS	PASS

CFCC Zn-Ni Path Forward

- **Conduct hydrogen embrittlement and hydrogen re-embrittlement testing**
- **Optimize process for select candidates**
  - Assess impact of operating parameters on key performance criteria (e.g., adhesion, corrosion resistance, appearance)
- **Conduct additional performance tests**
  - Evaluate fatigue effects on substrates, sulfur dioxide corrosion resistance, coating stripping performance, and brush plating repair
- **Perform tech transition activities**
  - Conduct a cost-benefit analysis
  - Execute demonstration/validation testing

C-5 Bogie Beam – Targeted Component for Zn-Ni Plating

Replacing Chromate Conversion Coatings Used on Aluminum

Identify and evaluate a CFCC for use on aluminum (Al) and Al-clad substrates at Oklahoma City ALC (OC-ALC)

Conversion Coating	Coating Process Identification
CCC, Cr(VI) conversion coating, vendor 1	Baseline 1
CCC, Cr(VI) conversion coating, vendor 2	Baseline 2
CFCC, water-based organic compound	Benchmark
CFCC, permanganate solution	Candidate 1
CFCC, inorganic fluoride	Candidate 2
CFCC, inorganic fluoride	Candidate 3

Aluminum CFCC Test Results

Conversion Coating	Alloy	Quality/Appearance	Corrosion Resistance, Hours to Failure (OC-ALC Process)	Dry Tape Adhesion, Primer 1, Rating	Dry Tape Adhesion, Primer 2, Rating
Baseline 1	2024	Pass	48	5A	4A-2A
	5052	Pass	168+	5A	5A-3A
	6061	Pass	168+	5A	5A - 3A
	7075	Pass	168+	5A	5A - 4A
Baseline 2	2024	Pass	48	5A	4A-2A
	5052	Pass	48-72	5A	5A
	6061	Pass	72-168	5A	5A
	7075	Pass	168+	5A	5A - 4A
Benchmark	2024	Pass	24	5A	5A
	5052	Pass	24	5A	5A - 4A
	6061	Pass	24	5A	5A
	7075	Pass	24	5A	5A - 4A
Candidate 1	2024	Pass	24	5A	5A
	5052	Pass	168+	5A	5A - 4A
	6061	Pass	168+	5A	5A - 4A
	7075	Pass	24	5A	5A
Candidate 2	2024	Pass	24	5A	4A - 3A
	5052	Pass	48	5A	5A - 4A
	6061	Pass	48	5A	5A - 3A
	7075	Pass	72-168	5A	5A
Candidate 3	2024	Pass	24	5A	4A - 2A
	5052	Pass	168+	5A	5A
	6061	Pass	168+	5A	5A - 3A
	7075	Pass	168+	5A	5A - 4A

	5 pits or less were seen in a total of 30 in^2 (Pass)
	5 to 7 pits were seen in a total of 30 in^2 (Marginal Fail)
	7 or more pits were seen in a total of 30 in^2 (Fail)

	Pass
	Marginal Fail
	Fail

Aluminum CFCC Path Forward

- **Continue performance testing**
  - Compare performance of conversion coatings using a modified OC-ALC process against a COTS cleaning process
  - Evaluate the two baselines
  - Evaluate two best performing candidates – Candidates 1 and 3
- **Assist OC-ALC with transition to most promising candidate**

TF-33 engine, containing parts coated with CCCs by OC-ALC

Next Generation Non-Line-of-Sight (NLOS) Coatings for Landing Gear Applications

Select and evaluate electroplated hard chromium (EHC) coating alternatives for NLOS landing gear (LG) applications

NLOS Coating	Coating Process Identification
Electroplated Hard Chromium	Baseline 1
Cobalt-Phosphorus	Benchmark
Nickel-Phosphorus w/Silicon Carbide	Candidate 1
Cobalt-Phosphorus w/Silicon Carbide	Candidate 2
Cobalt-Phosphorus w/Wear Additive	Candidate 3

NLOS Performance Test Results

Test	Test Method	EHC (Baseline)	Co-P Benchmark	Candidate 1	Candidate 2
Quality	AMS 2460	PASS	PASS	PASS	PASS
Fatigue Debit	ASTM E 466	Testing in Progress			
Hydrogen Embrittlement (As-plated)	ASTM F 519	PASS	Testing in Progress	PASS	PASS
Advanced Grinding	Vendor Method	Test cancelled due to warped panels			
Fluid Corrosion Resistance	ASTM F 483	PASS (All fluids passed)	FAIL (2 fluids failed)	MARGINAL (1 fluid failed)	MARGINAL (1 fluid failed)
Evaluation of Coatings Deposited on a Complex Geometry					
Thickness (mils)	ASTM B 487 ASTM B 499	FAIL (5.2 to 12.4)	MARGINAL (3.5 to 3.9)	PASS (2.9 to 3.2)	MARGINAL (4.7 to 6.0)
Hardness (Vickers)	ASTM E 384 ASTM B 487	FAIL (835)	FAIL (552)	FAIL (663)	FAIL (752)
Knife Adhesion	ASTM B 571	PASS	FAIL	PASS	PASS
Salt Fog Corrosion Resistance (120 hr)	ASTM B 117	Avg. Rating: 0 (48 hours to red rust)	Avg. Rating: 10 (No red rust)	Avg. Rating: 9 (No red rust)	Avg. Rating: 10 (No red rust)
Evaluation of Coating Stripping Processes					
Stripping Rate (mil/hr)	Vendor Method	PASS (2.9)	MARGINAL (0.3)	MARGINAL (0.4)	PASS (5.5)
Adhesion of Re-Plated Coupons	ASTM B571	Plating in progress			
Hydrogen Embrittlement of Re-Plated Coupons	ASTM F 519	Plating in progress			

NLOS Path Forward

- **Work with LG vendor to conduct additional testing and tech transition activities for best candidate**
- **Evaluate new nano-Co-P + wear additive coating for OO-ALC**
- **Work with OO-ALC on tech transition of best candidate**
  - Select a best candidate based on cost and technical factors
  - Perform a high-level cost-benefit analysis to compare candidates
  - Perform demonstration/validation and qualification testing

EHC Plating Line

Ionic Liquids Aluminum Electroplating

Evaluate ionic liquid-based electrodeposition of Al as an alternative to toluene-bath Al electroplating and Cd plating

Coating Method and Composition	Coating Process Identification
Electroplated Aluminum, toluene bath	Baseline 1
Ion Vapor Deposited Aluminum	Baseline 2
Electroplated Aluminum, ionic liquid bath	Candidate 1
Electroplated Aluminum alloy, ionic liquid bath	Candidate 2
Electroplated Aluminum, ionic liquid bath	Candidate 3

Ionic Liquids High-Strength Steel Testing Results

Test	Baseline		Ionic Liquids				
	Baseline 1	Baseline 2	Candidate 1, Set 1	Candidate 1, Set 2	Candidate 2, Set 1	Candidate 2, Set 2	CTC
Quality (Visual inspection)	PASS	PASS	PASS	FAIL	MARGINAL	PASS	PASS
Thickness (Target 1-1.5 mils)	PASS	PASS	FAIL (Thin)	PASS	FAIL (Thin)	FAIL (Thin)	PASS
Cross-Section Thickness (1-1.5 mils)	PASS	PASS	FAIL (Thin)	PASS	FAIL (Thin)	FAIL (Thin)	PASS
Composition (99%+ Al)	PASS	PASS	PASS	Not Tested	Deliberately Alloyed Al-Mn-Zr	Deliberately Alloyed Al-Mn-Zr	PASS
Salt Fog Corrosion Resistance (No red rust in 504 hours)	FAIL	PASS	PASS	Not Tested	PASS	Not Tested	Not Tested
Porosity (Fewer pits than Baseline 1)	PASS (2-10)	PASS (1-2)	FAIL (15-25)	Not Tested	PASS (0-4)	Not Tested	Not Tested
Adhesion (No separation from substrate)	PASS	FAIL	FAIL	FAIL	FAIL	MARGINAL	MARGINAL

Ionic Liquids Alternate Substrates Testing Results

Test	Alternate Substrates and Candidate 3	
	2024 Aluminum	1010 Steel
Quality (Visual inspection)	PASS	PASS
Thickness (Target 1-1.5 mils)	FAIL (4.65 – 5.83 mils)	PASS
Adhesion (No separation from substrate)	PASS	PASS

Indium-Zinc and Zinc-Nickel Alloys as Cadmium Brush Plating Replacements

Identified, evaluating, and initiating implementation activities for a Cd brush plating repair alternative

Coating	Coating Process Identification
Electroplated cadmium	Baseline 1
Vendor 1 zinc-nickel brush plating system	ZN-1
Vendor 2 zinc-nickel brush plating system	ZN-2
Vendor 3 zinc-nickel traditional brush plating system	ZN-3 (traditional)
Vendor 3 zinc-nickel specialized brush plating system	ZN-3 (specialized)
Vendor 2 indium-zinc brush plating system	IZ-1
Vendor 4 indium-zinc brush plating system	IZ-2

In-Zi and Zn-Ni Composition and Thickness

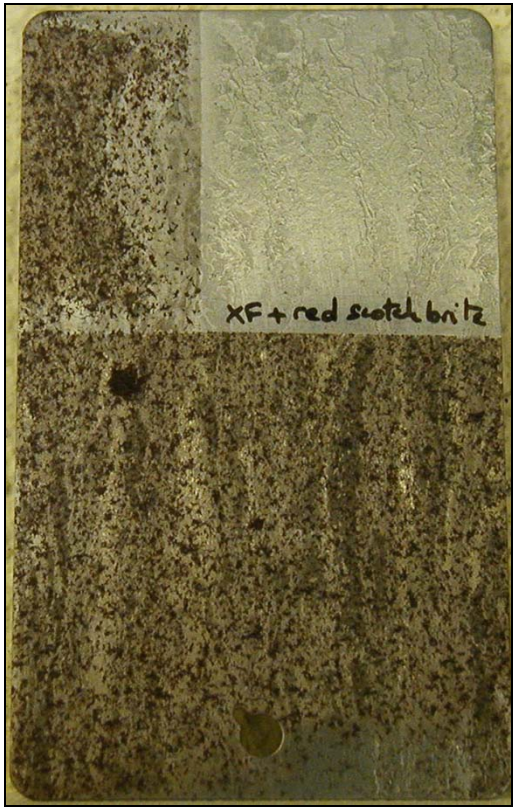
Coating	Target Composition (weight %)	Actual Composition (weight %)	Thickness (mil)
Baseline	Cd: 100	Cd: 100	0.54 ± 0.05
ZN-1	Zn: 92-80 Ni: 8-20	Zn: 88 ± 2 Ni: 12 ± 2	0.55 ± 0.04
ZN-2	Zn: 92-80 Ni: 8-20	Zn: 89 ± 2 Ni: 10 ± 1	0.61 ± 0.11
IZ-1	In: 70-60 Zn: 30-40	In: 63 ± 5 Zn: 34 ± 5	0.54 ± 0.13
IZ-2	In: 60-40 Zn: 60-40	In: 59 ± 8 Zn: 41 ± 8	0.65 ± 0.11
ZN-3 (specialized)	Zn: 92-80 Ni: 8-20	Zn: 88 ± 0.3 Ni: 12 ± 0.3	0.51 ± 0.04
ZN-3 (traditional)	Zn: 92-80 Ni: 8-20	Zn: 88 ± 0.6 Ni: 12 ± 0.6	0.50 ± 0.06

Indium-Zinc and Zinc-Nickel Testing Summary

Test		Cd (Baseline)	ZN-1	ZN-2	IZ-2	IZ-1	ZN-3 (Specialized)	ZN-3 (Traditional)
Adhesion		Pass	Marginal	Marginal	Pass	Pass	Pass	Pass
Resistance/Impedance (As-plated, prior to aging) , mΩ	DC	0.88	0.89	0.27	0.15	0.95	0.55	0.54
	1MHz	36	26	24	7.9	50	38	30
Resistance/Impedance (As-plated, prior to temperature cycling), mΩ	DC	7.54	20.78	15.18	Not tested	18.24	Not tested	Not tested
	1MHz	8.41	21.16	16.39	Not tested	19.30	Not tested	Not tested
Resistance/Impedance (Aged), mΩ	DC	3.6	5.3	172	0.45	88	3.7	5.6
	1MHz	35	32	217	7.5	112	26	24
Resistance/Impedance (Temperature cycled), mΩ	DC	0.85	3.0	5.4	Not tested	3.4	Not tested	Not tested
	1kHz	1.0	3.2	5.5	Not tested	3.5	Not tested	Not tested
Corrosion Resistance Salt Spray Rating	Scribed	9	9	8	Not tested	Too severe to evaluate	10	10
	Unscribed	8	7	9	Not tested	3	10	10
Wear (500 Cycles)	COF	0.32 ± 0.06	0.20 ± 0.03	0.23 ± 0.12	Not tested	0.55 ± 0.17	Not tested	Not tested
	Ranking	3.0 ± 0.4	2.0 ± 0.0	2.3 ± 0.3	Not tested	4.3 ± 0.9	Not tested	Not tested
Wear (5,000 Cycles)	COF	0.44 ± 0.02	0.43 ± 0.07	0.45 ± 0.21	Not tested	0.66 ± 0.11	Not tested	Not tested
	Ranking	4.5 ± 0	2.5 ± 0.4	3.3 ± 0.9	Not tested	5.0 ± 0	Not tested	Not tested
Whisker Growth (for informational purposes only)		No whiskers present	No whiskers present	No whiskers present	Whisker present before testing	Whisker present at 2000 hrs	Not tested	Not tested
		No whiskers present	No whiskers present	No whiskers present	Whisker present before testing	Whisker present at 2000 hrs	Not tested	Not tested

Indium-Zinc and Zinc-Nickel Path Forward

- **Continue testing ZN-3 candidate**
  - ZN-3 (specialized) performed well in impedance and corrosion tests
  - Further tests will include reparability and suitability to weapon system
- **Continue testing ZN-3 specialized apparatus**
  - Transition the ZN-3's specialized brush plating equipment for depot implementation
    - Equipment removes Cd and rust
  - Conduct Cd Type II reparability testing



Removal of rust and Cd using the specialized brush plating equipment

Summary

- **Regulations are becoming more stringent and needs for alternatives more imperative**
- **International regulations are driving U.S. regulations**
  - Used for regulatory outlook prospectus
- **Continuous improvement is essential to maintain compliance and ensure process or material sustainability**
- **Alternative materials are being considered for replacement**
- **AFRL is proactively investigating next-generation alternatives, where possible and defendable**

Contacts

Elizabeth S. Berman, Ph.D.
USAF AFMC AFRL/RXSC
Pollution Prevention Group
Materials & Manufacturing Directorate
Air Force Research Laboratory
2179 12th St, Ste 122
WPAFB, OH 45433
Phone: (937) 656-5700
Elizabeth.Berman@wpafb.af.mil

Melissa Klingenberg, Ph.D.
Concurrent Technologies Corporation
100 *CTC* Drive
Johnstown, PA 15904
Phone: (814) 269-6415
E-mail: **klingenb@ctc.com**

Natasha Voevodin, Ph.D.
USAF AFRL/RXSC (UDRI)
Pollution Prevention Group
Materials & Manufacturing Directorate
Air Force Research Laboratory
2179 12th St, Ste 122
WPAFB, OH 45433
Phone: (937) 656-5699
E-mail: **natasha.voevodin@wpafb.af.mil**

BACK UP SLIDES

Short-Term Environmental Drivers

- **Environmental**
  - Upcoming EPA Aerospace Residual Risk Rule could establish stricter emissions standards for aerospace surface finishing operations
  - Greenhouse gas emissions reduction, monitoring, and permitting requirements at EPA and DoD levels may add new compliance costs and concerns
  - New emissions standards for hazardous air pollutants from boilers and incinerators may create a significant compliance burden
- **Occupational Safety and Health Administration (OSHA)**
  - Annual Federal Agency Targeting Inspection Program (FEDTARG) is focusing on specific DoD locations experiencing an elevated number of work-related injuries and illnesses
  - Notices of Unsafe and Unhealthful Working Conditions have been issued to several USAF facilities over past 2 years
    - Unwelcome PR and additional compliance costs

Dichromate Sealer Replacement

Objective

- Identify, demonstrate/validate, and implement an alternative to sodium dichromate sealer for anodizing

Accomplishments

- Identified alternatives to sodium dichromate seal
- Evaluated alternative sealers through screening and performance tests
- Conducted a cost-benefit analysis
- Conducting additional testing requested by OO-ALC
- Conducting technology transfer activities

Typical Type II Anodizing Operation

Goal

AFRL Goal

- Eliminate hexavalent chromium (Cr[VI]) emissions in response to:
  - EO 13423 and EO 13514
  - DoD Memo “Minimizing the Use of Hexavalent Chromium” – April 2009

How Project Responds to Goal

- Eliminates Cr(VI) usage in OO-ALC’s anodizing process
  - Identifies and evaluates commercial sealer alternatives
  - Reduces ESOH concerns associated with Cr(VI) use
  - Collects and analyzes cost, material, environmental, and other process requirements
  - Updates military specification and Technical Orders to enable process improvements

Candidates

Sealer	Coating Process Identification
Sodium dichromate solution, 5-9 oz/gal	Baseline 1
Boiling deionized water	Baseline 2
Unsealed	Baseline 3
Sodium dichromate solution, 50 parts per million (ppm)	Benchmark
Permanganate Seal	Candidate 1
Low Nickel Seal (with a hot water seal)	Candidate 2A
Low Nickel Seal	Candidate 2B

Chromium-Free Conversion Coatings for Zinc-Nickel

Objective

- Identify and evaluate a chromium-free conversion coating (CC) for the zinc-nickel (Zn-Ni) plating line at Ogden Air Logistics Center (OO-ALC)
  - Replace trivalent chromium (Cr[III]) CC used on baseline
  - Should be applicable to all Zn-Ni processes in the USAF

Accomplishments

- Identified Cr-free Candidate 2-S1 as a promising replacement for Cr(III) baseline
- Completed quality, chemical composition, and extended (3,020-hour) ASTM B117
- Conducting hydrogen embrittlement and hydrogen re-embrittlement tests

C-5 Bogie Beam – Targeted Component for Zn-Ni Plating

Goal

AFRL Goal

- Eliminate use of Cr(III) in response to:
  - EO 13423 and EO 13514
  - DoD Memo "Minimizing the Use of Hexavalent Chromium" – April 2009
  - ESOH concerns

How Project Responds to Goal

- Eliminates Cr(III) from Zn-Ni processing at OO-ALC
  - Collects cost, material, environmental, and other process requirements
  - Identifies commercially available and developmental conversion coatings suitable for Zn-Ni

Candidates

Coating Process	Conversion Coating Composition	Secondary Sealer
Baseline	Cr(III) base	None
Candidate 1-S	Permanganate base	Inorganic silicate
Candidate 1	Permanganate base	None
Candidate 2-S1	Fluorozirconate base	Organic silicate
Candidate 2-S2	Fluorozirconate base	Inorganic silicate
Candidate 2	Fluorozirconate base	None
Candidate 3	Divalent Zn salt base	None

Replacing Chromate Conversion Coating Used on Aluminum

Objective

- Identify and evaluate a chromium-free conversion coating (CFCC) for use on aluminum (Al) and Al-clad substrates at Oklahoma City Air Logistics Center (OC-ALC)

Accomplishments

- Performed quality, corrosion, and tape adhesion tests
- Performed additional corrosion testing with CFCCs applied at new parameters requested by OC-ALC
- Identified two candidates, candidates 1 and 3
- Reviewed results with OC-ALC and CFCC vendors

Chromate conversion coating tank used at OC-ALC

Goal

AFRL Goal

- Eliminate Cr[VI] emissions in response to:
  - EO 13423 and EO 13514
  - DoD Memo "Minimizing the Use of Hexavalent Chromium" – April 2009
  - ESOH concerns

How Project Responds to Goal

- Eliminates use of chromium in metal finishing and painting processes at OC-ALC
  - Identifies commercially available and developmental CFCCs suitable for Al

Candidates

Conversion Coating	Coating Process Identification
CCC, Cr(VI) conversion coating, vendor 1	Baseline 1
CCC, Cr(VI) conversion coating, vendor 2	Baseline 2
CFCC, water-based organic compound	Benchmark
CFCC, permanganate solution	Candidate 1
CFCC, inorganic fluoride	Candidate 2
CFCC, inorganic fluoride	Candidate 3

Aluminum CFCC Screening Test Results

OC-ALC process vs. “Modification 1” OC-ALC Process

Conversion Coating	Alloy	OC-ALC Processed Panels, Failure Point (>5 spots)	"Modification 1" OC-ALC Processed Panels, Failure Point (>5 spots)
Baseline 1	2024	48 Hours	
	5052	168+ Hours	
	6061	168+ Hours	
	7075	168+ Hours	
Baseline 2	2024	48 Hours	
	5052	48-72 Hours	72-168+ Hours (5 pits on one panel at 48 hours, but then no more)
	6061	72-168 Hours	168+ Hours (5 pits on one panel at 48 hours, but then no more)
	7075	168+ Hours (1 failure at 72 hours)	168+ Hours
Benchmark	2024	24 Hours	
	5052	24 Hours	
	6061	24 Hours	
	7075	24 Hours	
Candidate 1	2024	24 Hours	24 Hours
	5052	168+ Hours	168+ Hours
	6061	168+ Hours	24-48 Hours
	7075	24 Hours	24 Hours
Candidate 2	2024	24 Hours	24 Hours
	5052	48 Hours	24 Hours
	6061	48 Hours	24 Hours
	7075	72-168 Hours	24 Hours
Candidate 3	2024	24 Hours	24 Hours
	5052	168+ Hours	48 Hours
	6061	168+ Hours	48 Hours
	7075	168+ Hours (1 failure at 168 hours)	24-72 Hours

	5 pits or less were seen in a total of 30 in^2 (Pass)
	5 to 7 pits were seen in a total of 30 in^2 (Marginal Fail)
	7 or more pits were seen in a total of 30 in^2 (Fail)

Next Generation Non-Line-of-Sight (NLOS) Coatings for Landing Gear Applications

Objective

- Utilize previously gathered coating data to select and evaluate electroplated hard chromium (EHC) coating alternatives for non-line-of-sight (NLOS) landing gear (LG) applications

Accomplishments

- Completed screening tests (quality, corrosion, wear) and identified two candidate coatings
- Performed a majority of performance tests evaluating the candidates on complex geometries and in stripping/re-plating maintenance scenarios

EHC Plating Line

Goal

AFRL Goal

- Eliminate use of chromium in response to:
  - EO 13423 and EO 13514
  - DoD Memo "Minimizing the Use of Hexavalent Chromium" – April 2009
  - ESOH concerns

How Project Responds to Goal

- Eliminates use of chromium from plating line at LG OEM and OO-ALC by 100%
  - Examines technical performance and processing logistics
  - Evaluates cost feasibility

Candidates

Conversion Coating	Coating Process Identification
Electroplated Hard Chromium	Baseline 1
Cobalt-Phosphorus	Benchmark
Nickel-Phosphorus w/Silicon Carbide	Candidate 1
Cobalt-Phosphorus w/Silicon Carbide	Candidate 2

Ionic Liquids Aluminum Electroplating

Objective

- Evaluate ionic liquid-based electrodeposition of aluminum as alternative to AlumiPlate™ and cadmium (Cd) plating

Accomplishments

- Evaluated multiple ionic liquid electroplating systems
- Demonstrated aluminum plating from ionic liquids and tested coating quality
- Confirmed need for further technology development
- Identified and evaluated critical plating variables
- Confirmed coating viability on multiple substrates

CTC-produced, aluminum-plated 4130 steel coupon: adherent, bright, and smooth

Goal

AFRL Goal

- Eliminate Cd and other toxic materials in response to:
  - EO 13423 and EO 13514
  - ESOH concerns

How Project Responded to Goal

- Validated a technology that can reduce Cd in coating operations and reduce toluene use in aluminum plating
  - Evaluated several ionic liquid electroplating technologies for Al plating
  - Provided groundbreaking ionic liquid-deposited coating data related to DoD requirements

Candidates

Conversion Coating	Coating Process Identification
Electroplated Aluminum, toluene bath	Baseline 1
Ion Vapor Deposited Aluminum	Baseline 2
Electroplated Aluminum, ionic liquid bath	Candidate 1
Electroplated Aluminum alloy, ionic liquid bath	Candidate 2
Electroplated Aluminum, ionic liquid bath	CTC